1. Introduction

This paper presents the operational characteristics of the supervisory control and data acquisition system (SCADA) for the hybrid-electric vehicle (HEV) working stand. Realization of this system is essential part of creation the operational laboratory structure for testing the newly developed technological solution of the HEV.

In the Research Center of Engine and Automotive Engineering Josef Bozek (RCJB) at CTU in Prague has been ongoing project for development of hybrid electric drive. For that purpose, the experimental working stand has been created at the Department of Electric Drives and Traction at Faculty for Electrical engineering (FEE). Main innovative characteristics of this hybrid drive is using of super-capacitor (SC) as accumulation unit and electric power splitter (EPS).

Proving the eligibility of this new technological solution has been obtained thought the creation of the mathematical model and computer simulation. The results show that this new concept of the vehicle enables standard passenger cars to consume almost 50% less fuel in urban driving and less then 20% in highway. Improving the fuel efficiency of the passenger vehicles is the ultimate goal of entire scientific and technical community. The main purpose of the hybrid electric drive is achievement of higher efficiency in energy transmission from internal combustion engine (ICE) to the traction wheels of the vehicle. The hybrid electric vehicle (HEV) represents the transient solution from standard internal combustion engine driven cars to all-electric driven vehicles (EV).

Some car manufacture companies already have successful commercial models, but all are based on significant different technological solution. Commercial hybrid electric cars, for splitting energy from ICE are using the planetary gear and separate electrical generator for electrical power supply of the traction motor and charging of the battery (Toyota Prius). In the hybrid electric system developed on the CTU Prague, the power splitting is performed entirely electrically by using the EPS. In addition, instead of chemical battery for accumulation of the breaking kinetic energy, in this working stand it is used the super-capacitor as new technological element for electrical energy storage.

The final step in proving of this technical concept is experimental verification within laboratory conditions. Therefore, the laboratory-working stand is created. The SCADA is essential part of this stand as a solution for real-time measuring and control of this complex testing structure.

2. Technical solution of the HEV with electric power splitter

The technological concept of HEV with EPS and super-capacitor is represented on Fig. 1. The internal combustion engine is the main and only power source of the vehicle that pro-
duces the mechanical power $P_{\text{Ice}}$. EPS is specially constructed synchronous generator with two rotating parts. The main rotor is classic permanent magnet rotor and it is firmly coupled to the drive shaft of ICE. The other rotating part is functionally same as all other AC machines, but with capability of rotation, placed on bearings. This part of the EPS is firmly coupled to the transmission that leads to the car wheels and rotates with the speed proportional to the vehicle velocity (speed $V$). This technical solution enables the ICE to operate on most optimal revolutions during entire driving schedule without dependence on the vehicle speed.

Magnetic field between EPS stator and rotor is transmission medium that enables partial transformation of produced mechanical power $P_{\text{Ice}}$ from ICE to electrical power $P_{\text{epsel}}$. This interaction within EPS creates mechanical torque on stator side that is transmitted to vehicle transmission drive shaft. By this means, $P_{\text{Ice}}$ in EPS is divided into electrical $P_{\text{epsel}}$ and mechanical power $P_{\text{epsmh}}$. On the shaft of the EPS rotating stator the induction traction motor (TM) is inserted. TM represents the main electrical propulsion to the vehicle. EPS and TM are electrically connected through two traction AC/DC and DC/AC power converters for HEV with intermediate DC link circuit. On this DC circuit, a SC is connected via charging and discharging DC-DC power converter, which precisely regulates the power flow from DC circuit and supercapacitor.

![Fig. 1: HEV drive with electric power splitter](image)

The traction motor is powered by $P_{\text{el}}$ that is generated in EPS ($P_{\text{epsel}}$) and by additional power from SC ($P_{\text{sc}}$). This machine produces mechanical power $P_{\text{tm}}$, which with mechanical $P_{\text{epsmh}}$ added from EPS, is transmitted to the car wheels. When the car is braking, TM changes the function from motor to generator. By this way, car kinetic energy produces the decelera-
tion power that can be partially converted into electric energy, which is accumulated in the SC and in the future can be used for the next acceleration in following driving cycles.

3. Experimental verification of the HEV technological concept

In order to be tested the new technological solutions on this HEV concept, the experimental working stand is created in the laboratory for electric drives and traction at FEE-CTU in Prague. The scheme of this laboratory stand is shown on Fig.2. The main functional units of the stand are the same as the units of the HEV concept shown on Fig 1.

![Fig. 2: Schematic representation of the experimental working stand](image)

On this HEV laboratory model, ICE and the car wheels has been substituted with two regulated induction motors. Internal combustion engine is simulated by a controlled electric AC induction motor. Traction load is simulated with another controlled AC induction motor. The main working structure of the experimental stand is consisted of four electrical machines, as shown on Fig. 3:

![Fig. 3: Machines of the laboratory working stand of HEV for experimental analysis](image)

4. SCADA for HEV working stand

The HEV working stand can be efficiently used only if there is supervisory system that gives real-time information of all essential parameters of the stand. In addition, real-time control is necessary for synergetic use of all functional entities of the stand. Therefore, supervisory control and data acquisition system is created for HEV stand (HEV-SCADA).
The communication infrastructure and functional subsystems of this SCADA system is shown on Fig 4. The real-time measurement of all necessary electrical quantities of the system is achieved by emplacing the voltage and current transducers. The mechanical quantities of two shafts (ICE and TM shaft) are measured with two speed and torque transducers.

The main intelligent part of the SCADA is a supervisory computer system that gathers, acquires data of the stand, and sends control commands to the process. This subsystem is consisted of PC based platform with Windows XP/Vista operating system. Using standardized computer structure enables versatility of this SCADA system to be used in any PC based platform and gives options for further development and flexible upgrade according to the needs.

Significant contribution of creating this SCADA for the HEV working stand is enabling user-friendly human-machine interface (HMI) for the operating personnel. A HMI is the apparatus that presents process data to a human operator and through this the human operator monitors and controls the process.

Two remote terminal units (RTU) are used for connecting the sensors in the process, converting sensor signals to digital data and sending digital data to the supervisory system. For torque and speed transducers is used Spider8 data acquisition system. This unit gathers data from four sensors, speed (n_{ICE}) and torque (T_{ICE}) on ICE drive shaft and speed (n_{TM}) and torque (T_{TM}) on TM shaft. Sensor signal data is acquired then processed and send as one data-stream through RS232 output interface. By using the RS232-USB converter, this data-stream is connected to the supervisory computer of the SCADA.

For data acquisition of the electrical quantities has been constructed special RTU (Fig. 5). Sensor signals from voltage and current transducers are acquired by using two NI USB-6009 multifunction DAQ. These devices are directly connected to the supervisory computer of the SCADA by USB. Each of them has 4 analogue inputs, 2 analogue outputs and 12 digital inputs-outputs. Analogue inputs are interconnected and electronically adopted for signal gathering of the voltage and current transducers. Analogue outputs are precise 12-bit voltage signals that are used for process control. By converting these signals through analogue-pulse generators, the precise pulse signals are generated. First signal is used for control of the frequency converter (FC 1) of the “internal combustion engine”. The second signal enables pulse control of the frequency converter (FC 2) of the “brake”. Third signal is used for control of the trac-
This remote terminal unit also has function as distributed control unit (DCU). Because all this signal processing, data logging devices, sensor signal adaptation and control signal transformation is placed in one box set (Fig. 5) and it is main regulation unit for HEV working stand it is named - HEV Remote Terminal Control Set (HEV-RTCS).

5. Visual programming structure of the HEV-SCADA

For creation of the HEV-SCADA is used the software package LabVIEW 8.6. It provides a graphical programming environment for developing sophisticated measurement, test, and control systems. Human-machine interface for HEV is created within LabVIEW. The main control and visualization panel is shown on Fig. 6:
LabVIEW is used as a platform because it enables intuitive graphical programming for advanced analysis and data visualization. It offers universal and versatile equipment integration with hardware devices and provides built-in libraries. This characteristic enables integration of the remote terminal units Spider8 and HEV-RTCS (Fig. 4 & Fig. 6).

Sensor data from voltage and current transducers with two NI USB-6009 multifunction DAQ are by graphic programming processed and real-time values are acquired (Fig. 7):

Real-time data processing directly from measuring equipment enables visualization of the measured quantities in visual panels. Current ($I_{eps}$) and voltage ($U_{eps}$) from EPS and in DC link circuit ($I_{dc}$ and $U_{dc}$) are presented in time domain as oscilloscopic waveform (Fig. 8):
6. Vehicle performance substitution on the HEV stand

Using this highly dynamic SCADA measure and control system on the working stand, substitution of the car traction power ($P_{\text{car}}$) can be experimentally generated. That can be achieved with LabVIEW interface for vehicle parameters and traction power control (Fig. 9):

Kinematic model of the vehicle for performance simulation is calculated in real-time. During the motion (drive), the vehicle is affected by different forces, $F_{\text{air}}$ aerodynamic drag forces, $F_r$ rolling resistance forces, $F_s$ resistive gravity forces and $F_a$ acceleration force.
Aerodynamic resistance is represented thought a $F_{\text{air}}$ drag force that the vehicle must overcome at a certain speed. This term is proportional to the square of the speed of the vehicle ($V$) and speed of the wind ($V_{\text{wind}}$), therefore, tends to be small at low speeds, but increases rapidly with velocity.

Rolling resistance forces $F_r$ are depended on weight of the vehicle $m$, road resistance drag $f$ and angle of inclination $\alpha$. This force is constant regardless of the speed of the vehicle and tends to dominate at relatively low speeds.

Resistive gravity forces $F_s$ are the forces that propel (or decelerate) the vehicle on a non-zero angle of inclination $\alpha$. This force is positive (is in the same direction as rest of the resistive forces) when the vehicle is on up-hill climbing ($\alpha>0$). If the vehicle is moving downhill ($\alpha<0$), $F_s$ is negative and propels the vehicle.

The mass inertia of the vehicle is manifested thought the acceleration force $F_a$. It is non-zero only when the vehicle is accelerated ($a>0$) or decelerated ($a<0$) and has no effect under constant-speed cruising conditions ($a=0$).

Total required force $F_{\text{car}}$ at the wheels of the vehicle, in order to overcome all the resistive forces during the drive, is the sum of all above described forces:

$$F_{\text{car}} = F_a + F_r + F_{\text{air}} + F_s$$

The most essential physical value of the vehicle kinematical model is the total demanded car traction power $P_{\text{car}}$ on the car wheel. This power is directly depended from drag forces $F_{\text{car}}$ and actual vehicle velocity $V$:

$$P_{\text{car}} = F_{\text{car}} \cdot V$$

$P_{\text{car}}$ in calculated in real-time, according to the pre-set car specifications and measured revolutions (nbrake) on traction load shaft (Fig. 9). According to this value, the command signal thought HEV-RTCS (Fig. 4 & Fig. 5) is sent to the frequency converter (FC 2) that controls the induction motor, which substitutes the traction load.

7. Conclusions

Creation of the HEV-SCADA system has considerably increased the operational performance of the HEV laboratory working stand. Supervising the real-time information of all essential parameters of the stand enables control for synergetic use of all functional entities of the system.

Construction of the HEV-RTCS (Remote Terminal Control Set) enabled electric transducers signal processing and control signal transformation. This box set is unique structure of the HEV-SCADA as newly created equipment and it is result of the engineering creativity.

Choosing the LabVIEW as a software platform for SCADA offers universal and versatile equipment integration. To the operators enables intuitive graphical programming for advanced analysis and data visualization. This characteristics enables integration of more remote terminal unites and further development of the SCADA structure.

HEV-SCADA is operational and numerous tests are performing on the HEV working stand. The results obtained from the experiments are used for data analysis and providing working characteristics of each component of the HEV system. That leads to further development of this new technological solution for hybrid-electric vehicle.
8. References


